Normal zone propagation, protection and quench measurements in a YBCO pancake coil at 77 K and at 4.2 K in magnetic fields up to 10 T

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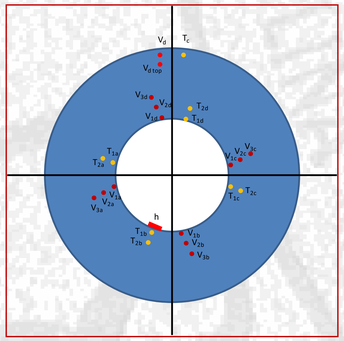
Abstract

We have measured stability, and normal zone propagation (NZP) in a YBCO pancake coil in liquid nitrogen bath (77.3 K) and in liquid helium bath (4.2 K). The experiments in liquid helium bath at 4.2 K were carried out in applied magnetic fields up to 10 T and at transport currents of a certain percentage of the coil critical current at a given field. The pancake coil was instrumented for voltage and temperature measurements at several places around the winding, such that both radial and azimuthal quench propagation could be measured. A heater was placed on the inner-most part of the winding. Heat pulses of various powers and durations were generated at different coil currents to measure quench and NZP. A protection circuit with a possibility of setting different quench voltage limits was used to protect the coil after quench.

Table 1: Coil parameters

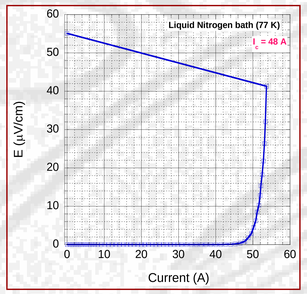
YBCO tape parameters				YBCO coil parameters				
Width (mm)	Thickness (mm)	Kapton insulation thickness (mm)	I_c (77K, self-field) (A)	Coil ID (mm)	Coil OD (mm)	Tape length in the coil (m)	Number of turns	Load during winding (kg)
4	0.13	0.01	100	30	39.3	3.41	31	9.25

Coil instrumentation



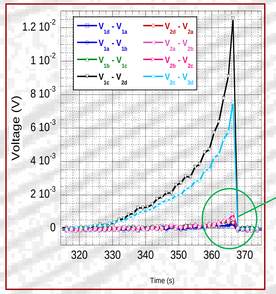
h – heater
V_{1a}, V_{1b}, V_{1c}, V_{1d} voltage taps 1st turn
V_{2a}, V_{2b}, V_{2c}, V_{2d} voltage taps on 6th turn
V_{3a}, V_{3b}, V_{3c}, V_{3d} voltage taps on 12th turn
$V_{d\ top}$ voltage tap on 31st turn (end of the winding)
V_d voltage tap on the current lead on top of the winding
T_{1a}, T_{1b}, T_{1c}, T_{1d} E-type thermocouples on 1st turn
T_{2a}, T_{2b}, T_{2c}, T_{1d} E-type thermocouples on 6th turn
T_d E-type thermocouple on the current lead on top of the winding

LN2 tests –self field

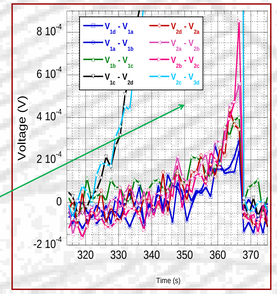


I-V curve of the coil ($V_{1d} - V_d$) (i.e. the whole winding of the coil) coil critical current = 48 A. Quench protection limit of 30 mV was set during the measurement $I_{c\ coil}$ = 0.455$I_{c\ tape}$ (which is 54.5% degradation)

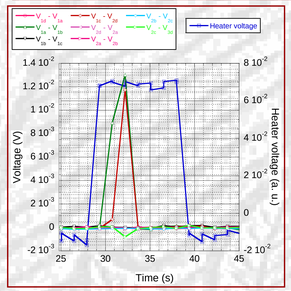
R_{heater} = 42.1 Ω



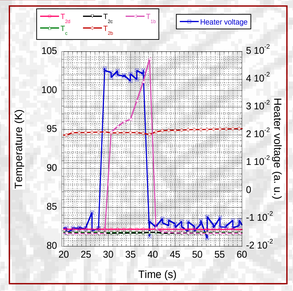
Simultaneous monitoring of individual voltage taps during the coil I-V measurement. Voltages detected on $V_{1c} - V_{2d}$ and $V_{2c} - V_{3d}$ which are positioned in the 1st quadrant of the coil winding cross-section, i.e. the quench occurred in 1st quadrant between 5th and 12th turn



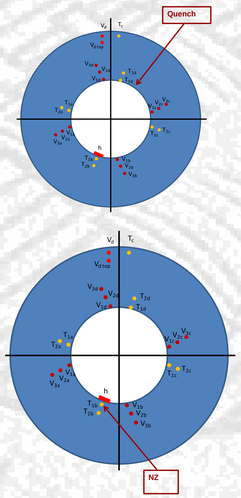
Heat pulses at I_{coil} = 39.6 A = 0.825$I_{c\ coil}$



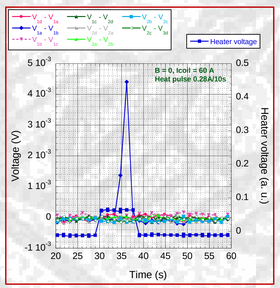
Voltage drops in the coil winding after applying a heat pulse of 0.3 A/10s. Voltage drop observed on tapes $V_{1a} - V_{1b}$ and $V_{1c} - V_{2d}$. Voltage taps $V_{1a} - V_{1b}$ are positioned above the heater. A sharp decrease of these voltages down to zero during the heat pulse duration indicates that the current in the coil was switched off by the protection circuit.



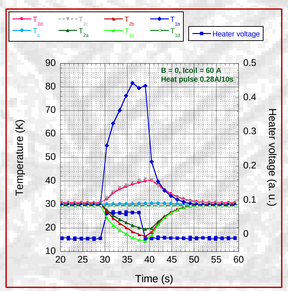
Temperature in the winding during a heat pulse of 0.2 A/10s (MQE = 16.84 J). Thermocouple T_{1b} is positioned on the heater (it shows max. temperature of about 104 K). Not propagating NZ is observed.



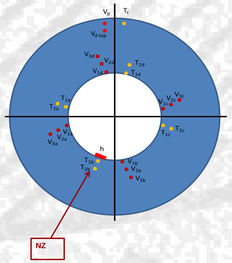
LHe tests – self field



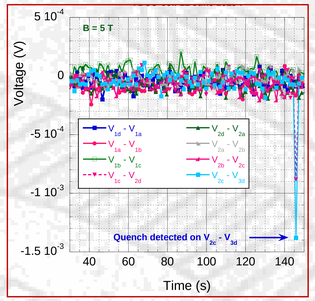
Voltage drops in the coil winding at 0 T and I_{coil} = 60 A after applying a heat pulse of 0.28 A with duration of 10 seconds. NZ observed just above the heater. Minimum quench energy = 33 J.



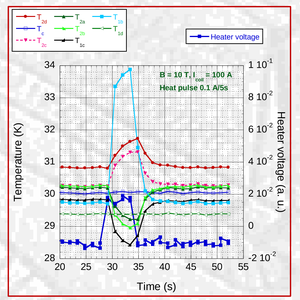
Temperature in the coil winding at 0 T and I_{coil} = 60 A after applying a heat pulse of 0.28 A with duration of 10 seconds. Non propagating NZ observed just above the heater with maximum temperature of 81.724 K. Minimum quench energy MQE = 33 J.



LHe tests up to 10 T

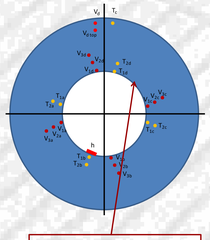


Voltage distribution in the coil winding at B = 5 T monitored during I-V curve measurement. Quench occurred at I = 74.7 A. Quench detected on voltage taps $V_{2c} - V_{3d}$ (1st quadrant of the winding, between 5th and 12th turn).

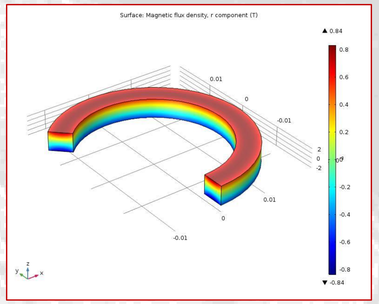


Temperature in the coil winding at 10 T and I_{coil} = 100 A after applying a heat pulse of 0.1 A with duration of 5 seconds. No NZ observed.

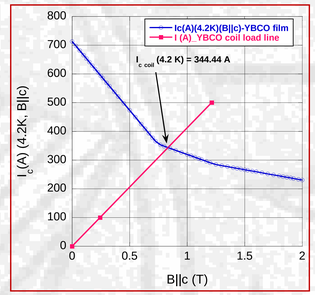
Run	B (T)	I_{quench} (A)
1	10	161.95
2	10	90.087
3	5	74.722
4	0	77.443



LFEM modeling – LHe, self-field



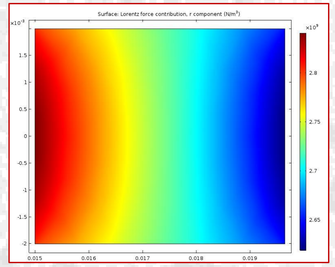
Radial magnetic field component on the coil surface at coil critical current $I_{c\ coil}$ = 344.44 A obtained from FEM modeling.



I_c of the tape vs. B, parallel to c-axis of the YBCO film, (blue open circles) and coil load line, i.e. the maximum B||c in the winding vs. coil current (solid red squares). The crossing point of these two dependencies determines the coil critical current $I_{c\ coil}$ = 344.44 A.

Conclusion

- I_c of the coil in self-field at 77 K was 48 A which is 45.5 % of the short sample I_c in self-field
- Spontaneous quenches occurred both at 77 K as well as at 4.2 K
- Spontaneous quenches were localized in the 1st quadrant of the winding, between 5th and 12th turn
- Heat pulses generated localized NZ just above the heater both at 77 K as well as at 4.2 K
- At 77 K and self field MQE = 16.84 J at I_{coil} = 39.6 A = 0.825$I_{c\ coil}$
- At 4.2 K and self-field MQE = 33.0064 J at I_{coil} = 60 A



Distribution of the radial Lorentz force component in the coil winding – I_q = 161.95 A, 10 T.

Acknowledgements

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